[0001]   BASE STATION FOR DISTANCE DETERMINATION

[0002]   This application is a continuation application of U.S. Patent Application No. 09/274,081, filed March 22, 1999.

[0003]   BACKGROUND

[0004]   Field of the Invention

[0005]   This invention generally relates to spread spectrum code division multiple access (CDMA) communication systems. More particularly, the present invention relates to a system and method that determines the geographic location of a subscriber unit within a CDMA communication system.

[0006]   Description of the Prior Art

[0007]   Wireless systems capable of locating a subscriber are presently known in the art. One wireless technique uses the global positioning system (GPS). In GPS, the communication handset receives data transmitted continuously from the 24 NAVSTAR satellites. Each satellite transmits data indicating the satellite's identity, the location of the satellite and the time the message was sent. The handset compares the time each signal was received with the time it was sent to determine the distance to each satellite. Using the determined distances between the satellites and the handset along with the location of each satellite, the handset can triangulate its location and provide the information to a communication base station. However, the incorporation of a GPS within a subscriber unit increases its cost.

[0008]   Another subscriber location technique is disclosed in U.S. Patent No. 5,732,354. A mobile telephone using time division multiple access (TDMA) as the air interface is located within a plurality of base stations. The mobile telephone measures the received signal strength from each of the base stations and transmits each strength to each

respective base station. At a mobile switching center, the received signal strengths from the base stations are compared and processed. The result yields the distance between the mobile telephone and each base station. From these distances, the location of the mobile telephone is calculated.

[0009]   Wireless communication systems using spread spectrum modulation techniques are increasing in popularity. In code division multiple access (CDMA) systems, data is transmitted using a wide bandwidth (spread spectrum) by modulating the data with a pseudo random chip code sequence. The advantage gained is that CDMA systems are more resistant to signal distortion and interfering frequencies in the transmission path than communication systems using the more common time division multiple access (TDMA) or frequency division multiple access (FDMA) techniques.

[0010]   There exists a need for an accurate mobile subscriber unit location system that uses data already available in an existing CDMA communication system.

[0011]   SUMMARY

[0012]   A base station transmits a first spread spectrum signal having a first code. It receives and analyzes an impulse response of multipath components of a second spread spectrum signal having a second code to determine a first received component. The second signal is time synchronized with the first spread spectrum signal. A distance determination is made based on in part a timing difference between the second code of the received second signal and the first code of the base station's transmitted first signal and the determined first received components for that base station's received second signal.

[0013]   BRIEF DESCRIPTION OF THE DRAWING(S)

[0014]   Figure 1 is an illustration of a simplified, prior art CDMA system.

[0015]   Figure 2 is an illustration of a prior art CDMA system.

[0016]   Figure 3 is a block diagram of major components within a prior art CDMA system.

[0017]   Figure 4 is a block diagram of components within a prior art CDMA system.

[0018]   Figure 5 is an illustration of a global pilot signal and an assigned pilot signal being communicated between a base station and a subscriber unit.

[0019]   Figure 6 is a block diagram of a first embodiment of the present invention using at least three base stations.

[0020]   Figure 7 is an illustration of locating a subscriber unit using the first embodiment of the present invention with at least three base stations.

[0021]   Figure 8 is a block diagram of a second embodiment of the present invention showing components used in a subscriber unit.

[0022]   Figure 9 is an illustration of locating a subscriber unit using the second embodiment of the present invention with two base stations.

[0023]   Figure 10 is an illustration of locating a subscriber unit using the second embodiment of the present invention with more than two base stations.

[0024]   Figure 11 is a detailed illustration of the third embodiment of the present invention having a base station with multiple antennas.

[0025]   Figure 12 is an illustration of the third embodiment having a base station with multiple antennas.

[0026]   Figure 13 is a block diagram of components used in the third embodiment.

[0027]   Figure 14 is an illustration of multipath.

[0028]   Figure 15 is a graph of a typical impulse response of multipath components.

[0029]   Figure 16 is a block diagram of components within a fourth embodiment correcting for multipath.

[0030] DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0031] The preferred embodiments will be described with reference to the drawing figures where like numerals represent like elements throughout.

[0032] Shown in Figure 1 is a simplified CDMA communication system. A data signal with a given bandwidth is mixed with a spreading code generated by a pseudo random chip code sequence generator producing a digital spread spectrum signal. Upon reception, the data is reproduced after correlation with the same pseudo random chip code sequence used to transmit the data. Every other signal within the transmission bandwidth appears as noise to the signal being despread.

[0033] For timing synchronization with a receiver, an unmodulated pilot signal is required for every transmitter. The pilot signal allows respective receivers to synchronize with a given transmitter, allowing despreading of a traffic signal at the receiver.

[0034] In a typical CDMA system, base stations send global pilot signals to all subscriber units within their communicating range to synchronize transmissions in a forward direction. Additionally, in some CDMA systems, for example a B-CDMA™ system, each subscriber unit sends a unique assigned pilot signal to synchronize transmissions in a reverse direction.

[0035] Figure 2 illustrates a CDMA communication system 30. The communication system 30 comprises a plurality of base stations 36_1, 36_2 ... 36_n. Each base station 36_1, 36_2 ... 36_n is in wireless communication with a plurality of subscriber units 40_1, 40_2 ... 40_n, which may be fixed or mobile. Each subscriber unit 40_1, 40_2 ... 40_n communicates with either the closest base station 36_1 or the base station 36_1 which provides the strongest communication signal. Each base station 36_1, 36_2 ... 36_n is in communication with other components within the communication system 30 as shown in Figure 3.

[0036] A local exchange 32 is at the center of the communications system 30 and communicates with a plurality of network interface units (NIUs) 34_1, 34_2 ... 34_n. Each NIU is in communication with a plurality of radio carrier stations (RCS) 38_1, 38_2 ... 38_n or base

stations 36_1, 36_2 ... 36_n. Each (RCS) 38_1, 38_2 ... 38_n or base station 36_1, 36_2 ... 36_n communicates with a plurality of subscriber units 40_1, 40_2 ... 40_n within its communicating range.

[0037]   Figure 4 depicts a block diagram of the pertinent parts of an existing spread spectrum CDMA communication system. Each independent base station 36_1, 36_2 ... 36_n generates a unique global pilot signal using a global pilot chip code generating means 42_1 and spread spectrum processing means 44_1. The global pilot chip code generating means 42_1 generates a unique pseudo random chip code sequence. The unique pseudo random chip code sequence is used to spread the resultant signals bandwidth such as to 15 MHZ as used in the B-CDMA™ air interface. The spread spectrum processing means modulates the global pilot chip code sequence up to a desired center frequency. The global pilot signal is transmitted to all subscriber units 40_1 by the base station's transmitter 46_1.

[0038]   A receiver 48_1 at a subscriber unit 40_1 receives available signals from a plurality of base stations 36_1, 36_2 ... 36_n. As shown in Figure 5, the global pilot 50_1 travels from the base station 36_1 to the subscriber unit 40_1 and can be represented as:

$$\tau_l = \frac{\underline{d}_1}{c}$$ Equation (1)

The time the signal travels from the base station 36_1 to the subscriber unit 40_1, τ_l, equals the distance between the base station 36_1 and subscriber unit 40_1, d_l, divided by the speed of light, c.

[0039]   Referring back to Figure 4, a global pilot chip code recovery means 54_1 within the subscriber unit 40_1 can receive global pilot chip code sequences from a plurality of base stations 36_1, 36_2 ... 36_n. The subscriber unit 40_1 generates a replica of a global pilot chip code sequence and synchronizes the generated replica's timing with the received global pilot

50_1. The subscriber unit 40_1 also has a processor 82_1 to perform the many analysis functions of the subscriber unit 40_1.

[0040]	The subscriber unit 40_1 generates an assigned pilot signal 52_1 using assigned pilot chip code generating means 56_1 and spread spectrum processing means 58_1. The assigned pilot chip code generating means 56_1 generates a pseudo random chip code sequence with its timing synchronized with the recovered global pilot chip code sequence. As a result, the assigned pilot chip code sequence is delayed by τ_1 with respect to the base station 36_1, 36_2 ... 36_n. The spread spectrum processing means 58_1 generates the assigned pilot signal 52_1 by modulating the assigned pilot chip code sequence up to a desired center frequency. The assigned pilot signal 52_1 is transmitted to all base stations 36_1, 36_2 ... 36_n within range to receive the assigned pilot signal 52_1.

[0041]	The base station 36_1 receives the assigned pilot signal 52_1 with the base station's receiver 62_1. The received assigned pilot 52_1 travels the same distance d_1 as the global pilot signal 50_1 as shown in Figure 5. Accordingly, the received assigned pilot signal will be delayed by τ_1 with respect to the mobile unit 40_1 and by $2\tau_1$ with respect to the global pilot 50_1 generated at the base station 36_1.

[0042]	Since the chip code sequence of the assigned pilot 52_1 received at the base station 36_1 will be delayed by $2\tau_1$ with respect to the chip code sequence of the global pilot signal 50_1 generated at the base station 36_1, the round trip propagation delay, $2\tau_1$, can be determined by comparing the timing of the two chip code sequences. Using the round trip propagation delay, $2\tau_1$, the distance d_1 between the base station 36_1 and subscriber unit 40_1 can be determined by:

$$d_1 = c \cdot \frac{2\tau_1}{2}.$$

<div align="right">Equation (2)</div>

If a spreading sequence having a chipping rate of at least 80ns is used and the communication system has the ability to track $1/16^{th}$ of a chip, the distance d_1 can be measured to within 2 meters.

[0043]   Figure 6 is a block diagram of a first embodiment of the present invention. No additional hardware is required in the subscriber unit 40_1. The only changes are implemented by software within the subscriber unit's processor 82_1 and the processors 66_1, 66_2 ... 66_n, 68, 70_1, 70_2 ... 70_n located within the base station 36_1, NIU 34_1 or Local Exchange 32_1, Precincts 74_1, 74_2 ... 74_n and Ambulance Dispatcher 76.

[0044]   The subscriber unit 40_1 is sent a signal by a base station 36_1 indicating that a 911 call was initiated and to begin the subscriber location protocol. Upon receipt, the subscriber unit 40_1 will sequentially synchronize its transmission chip code sequence to at least three base stations' chip code sequences. To allow reception by the base stations 36_2, 36_3 ... 36_n outside of the subscriber unit's normal communicating range, these transmissions will be sent at a higher than normal power level temporarily over-riding any adaptive power control algorithms.

[0045]   A processor 66_1 within each base station 36_1, 36_2 ... 36_n is coupled to the assigned pilot chip code recovery means 64_1 and the global pilot chip code generator 42_1. The processor 66_1 compares the two chip code sequences to determine the round trip propagation delay τ_1, τ_2 ... τ_n and the respective distance d_1, d_2 ... d_n between the subscriber unit 40_1 and the respective base station 36_1, 36_2 ... 36_n.   Within either a NIU 34_1 or the local exchange 32, a processor 68 receives the distances d_1, d_2 ... d_n from the processors 66_1, 66_2 ... 66_n within all the base stations 36_1, 36_2 ... 36_n. The processor 68 uses the distances d_1, d_2 ... d_n to determine the location of the subscriber unit 40_1 as follows.

[0046]   By using the known longitude and latitude from three base stations 36_1, 36_2, 36_3 and distances d_1, d_2, d_3, the location of the subscriber unit 40_1 is determined. As shown in Figure 7 by using the three distances d_1, d_2, d_3, three circles 78_1, 78_2, 78_3 with radiae 80_1, 80_2, 80_3 are constructed. Each circle 78_1, 78_2, 78_3 is centered around a respective base

station 36_1, 36_2, 36_3. The intersection of the three circles 78_1, 78_2, 78_3 is at the location of the subscriber unit 40_1.

[0047]   Using the Cartesian coordinates, the longitude and latitude corresponding with each base station 36_1, 36_2 ... 36_n is represented as X_n, Y_n, where X_n is the longitude and Y_n is the latitude. If X, Y represents the location of the subscriber unit 40_1, using the distance formula the following equations result:

$$(X_1\text{-}X)^2 + (Y_1\text{-}Y)^2 = d_1^2 \qquad\qquad \text{Equation (3)}$$

$$(X_2\text{-}X)^2 + (Y_2\text{-}Y)^2 = d_2^2 \qquad\qquad \text{Equation (4)}$$

$$(X_3\text{-}X)^2 + (Y_3\text{-}Y)^2 = d_3^2 \qquad\qquad \text{Equation (5)}$$

[0048]   In practice due to small errors in calculating the distances d_1, d_2, d_3, Equations 3, 4 and 5 cannot be solved using conventional algebra. To compensate for the errors, a maximum likelihood estimation is used to determine the location and are well known to those skilled in the art. For increased accuracy, additional base stations 36_4, 36_5 ... 36_n can be used to calculate additional distances for inclusion in the estimation analysis.

[0049]   The subscriber unit's location is sent through the communication system 30 to at least one precinct 74_1, 74_2 ... 74_n and an ambulance dispatcher 76. A processor 70_1 within each precinct 74_1, 74_2 ... 74_n and the ambulance dispatcher 76 receives the location of all 911 calls originating in the system and displays the location on a conventional computer monitor 72_1. The display comprises a listing of all 911 calls and addresses on a geographic map.

[0050]   An alternate approach reduces the number of processors by transmitting raw data through the communication system 30 and processing the raw data at a single site.

[0051]   Figure 8 is a second embodiment of a location system. At least two base stations 36_1, 36_2 ... 36_n have their internal timing synchronized with each other and transmit their respective global pilot signals 52_1, 52_2 ... 52_n with time synchronized chip code sequences. The subscriber unit 40_1 receives the global pilots 52_1, 52_2 ... 52_n. However, the received global pilots 52_1, 52_2 ... 52_n are not synchronized. The global pilot 52_1 from a first base station 36_1 will travel distance d_1 and is delayed by τ_1. The global pilot 52_2 from a second base station 36_2 travels distance d_2 and is delayed by τ_2. The subscriber unit 40_1 recovers each base station's global pilot chip code sequence with its global pilot chip code recovery means 54_1. A processor 82_1 within the subscriber unit 40_1 is coupled to each global pilot chip code recovery means 54_1, 52_2 ... 54_n. The processor 82_1 compares the chip code sequences of each pair of pilot chip code sequences and calculates the time differences Δt_1, Δt_2 ... Δt_n between the sequences as follows.

[0052]   Within the subscriber unit 40_1, the chip code sequences used by each base station 36_1, 36_2 ... 36_n are stored. After synchronizing with the first base station's pilot 36_1, the processor 82_1 will store where within the sequence synchronization was obtained. This process is repeated for the other base stations 36_2, 36_3 ... 36_n. The synchronization process can be done sequentially (synchronizing to the first base station's chip code sequence then the second, etc.) or in parallel (synchronizing to all base stations at the same time).

[0053]   By using the relative time difference between τ_1, τ_2, ... τ_n each base station's chip code sequence and knowing that each base station's pilot was sent at the same time, with two base stations the time differences are calculated as follows:

$$\Delta t_1 = \tau_2 - \tau_1 \qquad\qquad \text{Equation (6)}$$

$$\Delta t_2 = \tau_3 - \tau_2 \qquad\qquad \text{Equation (7)}$$

The time differences Δt_1, Δt_2 ... Δt_n are transmitted to at least one of the base stations 36_1.

[0054]   At least one base station 36_1 recovers the time difference data from the received signals using time difference recovery means 84_1. The time difference data is sent with the distance data d_1 through the communications system to a processor 68. The processor 68 determines the location of the subscriber unit 40_1 using the time difference data Δt_1, Δt_2 ... Δt_n and the distance data d_1, d_2 ... d_n as follows.

[0055]   Using information from only two base stations 36_1, 36_2 as shown in Figure 9, the processor uses distances d_1, d_2 to create two circles 78_1, 78_2. Using the time difference, Δt_1, a hyperbola 86_1 can be constructed as follows.

[0056]   All the points along the hyperbola 86_1 receive the global pilot signals 52_1, 52_2 from the synchronized base stations 36_1, 36_2 with the same time difference, Δt_1. The time difference Δt_1 can be converted to a distance difference Δd_1 by substituting Δt_1 for t_1 and Δd_1 for d_1 in Equation 1. Using the distance formula and X, Y as the location of the subscriber unit 40_1, the following equation results:

$$\Delta d_1 = \sqrt{(X_1 - X)^2 + (Y_1 - Y)^2} - \sqrt{(X_2 - X)^2 + (Y_2 - Y)^2} \qquad \text{Equation (8)}$$

[0057]   By using Equation 8 with Equations 3 and 4 in a maximum likelihood estimation, the location of the subscriber unit 40_1 can be determined. The subscriber unit's location is subsequently sent to the nearest police precinct 74_1, 74_2 ... 74_n and ambulance dispatcher 76 in the cellular area.

[0058]   For improved accuracy, additional base stations 36_1, 36_2 ... 36_n are used. Figure 10 shows the invention used with three base stations 36_1, 36_2, 36_3. The distances d_1, d_2, d_3 are used to create three circles 78_1, 78_2, 78_3. Using time differences Δt_1, Δt_2, two intersecting hyperbolas 86_1, 86_2 are constructed. With maximum likelihood estimation, the subscriber units' location calculated with two hyperbolas 86_1, 86_2, and three circles 78_1, 78_2, 78_3 yields greater accuracy.

[0059]   As shown in Figure 8, the subscriber unit 40_1 is required to process each global pilot chip code sequence to determine the time differences Δt_1, Δt_2 ... Δt_n. An alternate approach removes the processing from the subscriber unit 40_1.

[0060]   With reference to Figure 6, the mobile unit 40_1 will synchronize the assigned pilot to one of the base station's global pilot chip code sequences, such as the nearest base station 36_1 with a delay of τ_J. The assigned pilot 50_1 is transmitted to all base stations 36_1, 36_2 ... 36_n. The assigned pilot 50_1 will be received at each base station with a respective delay, $\tau_J + \tau_J$, $\tau_1 + \tau_2$, $\tau_J + \tau_3$. Each base station 36_1, 36_2 ... 36_n will send the delayed chip code sequence along with the calculated distance to a processor 68 located in a NIU 34_1 or local exchange 32. The processor 68 will calculate the time differences Δt_1, Δt_2 ... Δt_n by comparing the received assigned pilot chip code sequences. Since all received assigned pilot chip code sequences are delayed by τ_J, the τ_J delay will cancel out of the resultant time differences Δt_1, Δt_2 ... Δt_n. Accordingly, the subscriber unit 40_1 can be located using hyperbolas 86_1, 86_2 as previously described.

[0061]   Another embodiment shown in Figures 11, 12 and 13 uses a base station 36_1 with multiple antennas 88_1, 88_2 ... 88_n. Two of the antennas 88_1, 88_2 lie along a centerline 92 at a known distance, l, apart as shown in Figure 11. Both antennas 88_1, 88_2 receive the assigned pilot signal 90_1, 90_2 from the subscriber unit 40_1. However, the antenna 88_2 further away from the subscriber unit 40_1 receives the signal over a slightly longer distance d_J' and with a slight delay with respect to the nearer antenna 88_1. This delay results in a carrier phase difference, φ, between the signals received at each antenna as shown on Figure 13. A processor 66 using the received carrier phase difference and the chip code sequence recovered by each assigned pilot chip code recovery means 96_1, 96_2 ... 96_n can determine the location of the subscriber unit 40_1 as follows.

[0062]   As shown in Figure 12, the subscriber unit 40_1 is located at distance d_J at angle α from the centerline 92 of the antennas 88_1, 88_2. As seen at the scale of Figure 12 both received assigned pilot signals 90_1, 90_2 appear to be coincident. However, as shown in

Figure 11, the received assigned pilot signals 90_1, 90_2 are slightly separated. The received assigned pilot signal 90_1 returning to the first antenna 88_1 travels a distance d_I. The received assigned pilot signal 90_2 returning to the second antenna 88_2 travels a slightly longer distance d_I'. As shown in Figure 11, the difference between the two distances d_I, d_I' is a distance m.

[0063]   Since the distances d_I, d_I' between the antennas 88_1, 88_2 and the subscriber unit 40_1 are much larger than the distance l between the antennae 88_1, 88_2 both received assigned pilot signals 90_1, 90_2 follow approximately parallel paths. By constructing a right triangle using a point 94 which is distance d_I from the subscriber unit 40_1 as shown in Figure 11, the angle $\propto$ can be determined by the following geometric relationship:

$$\propto = COS^{-1}(m/l). \qquad \text{Equation (9)}$$

[0064]   The distance m can be determined by using the carrier phase difference, φ, between the two received signals 90_1, 90_2 as follows:

$$m = \frac{\phi \cdot \lambda}{2\pi} \qquad \text{Equation (10)}$$

The distance m equals the phase difference between the two signals, φ, in radians multiplied by the wavelength of the signal, λ, divided by 2π. The wavelength, λ, can be derived from the known frequency f of the assigned pilot signal as follows:

$$\lambda = c/f. \qquad \text{Equation (11)}$$

[0065]   The processor 68 also compares the chip code sequences of the global pilot generating means 42_1 with the recovered assigned pilot chip code sequence to determine the distance d_I as shown in Figure 6. Using both the angle $\propto$ and distance d_I, the processor 66_1

-12-

locates the subscriber unit 40_1 using simple geometry. There are many techniques well known to those skilled in the art to eliminate the ambiguity between locations above and below the antennas 88_1, 88_2. One such technique is using antennas employing sectorization. Subsequently, the subscriber unit's location is sent to the precincts 74_1, 74_2 ... 74_n and ambulance dispatcher 76. Additional antennas may be used to improve on the accuracy of the system.

[0066]   An alternate embodiment uses more than one base station 36_1, 36_2 ... 36_n. A processor 68 located within either a NIU 34_1 or the local exchange 32 collects distance and angle information from more than one base station 36_1, 36_2 ... 36_n as well as the time differences Δt_1, Δt_2 ... Δt_n, between the base stations 36_1, 36_2 ... 36_n. Using the maximum likelihood estimation technique, the processor 68 determines a more accurate location of the subscriber unit 40_1.

[0067]   A fourth embodiment corrects for multipath. Figure 14 illustrates multipath. A signal such as a global pilot signal is transmitted from a base station 36_1. The signal follows a multitude of paths 98_1, 98_2 ... 98_n between the base station 36_1 and subscriber unit 40_1.

[0068]   Figure 13 is a graph showing the impulse response 136 of the received multipath components. Since each received multipath component travels a unique path, it arrives at a receiver with a propagation delay determined by the length of the path 98_1, 98_2 ... 98_n. The impulse response 106 shows the collective signal magnitude of all the multipath components received at each propagation delay.

[0069]   The previously described subscriber unit location techniques assumed the subscriber unit 40_1 synchronizes with the line of sight multipath component 98_1 traveling distance d_l. However, if the subscriber unit synchronizes with a non-line of sight multipath component 98_1, 98_2 ... 98_n, the distance calculation will be in error due to the delay MD_1 as shown in Figure 15.

[0070]   Figure 16 is a system correcting for errors resulting from multipath. The global pilot 50_1 is sent from the base station 36_1 to subscriber unit 40_1. The subscriber unit 40_1 collects all of the multipath components using a multipath receiver 102_1 such as disclosed in U.S. Patent Application No. 08/669,769, Lomp et al., incorporated here by reference. A processor 82_1 within the subscriber unit 40_1 analyzes the impulse response 100 of the received global pilot signal 50_1.

[0071]   Since the line of sight multipath component 98_1 travels the shortest distance d_l, the first received component 98_1 is the line of sight component. If the line of sight component is not received, the first received component 98_1 will be the closest and, accordingly, the best available estimate for the line of sight component. The processor 82_1 compares the chip code sequence of the first received component 98_1 with the chip code sequence used to synchronize the assigned pilot chip code sequence. This comparison determines the delay due to multipath, MD_1. The multipath delay, MD_1, is transmitted to the base station 36_1.

[0072]   A processor 66_1 and multipath receiver 104_1 within the base station 36_1 perform the same analysis on the received assigned pilot signal. As a result, the multipath delay, MD_2, of the assigned pilot signal is determined. Additionally, multipath delay recovery means 106_1 recovers the transmitted global pilot signal's multipath delay MD_1 for use by the processor 66_1. The processor 66_1 compares the generated global pilot chip code sequence to the recovered assigned pilot chip code sequence to determine the round trip propagation delay $2\tau_l$. To correct for multipath, the processor 66_1 subtracts both the global pilot signal's multipath delay MD_1 and the assigned pilot signals multipath delay MD_2 from the calculated round trip propagation delay, $2\tau_1$. The corrected round trip propagation delay is used to determine the subscriber unit's location in one of the techniques as previously described.

[0073]   Although the invention has been described in part by making detailed reference to certain specific embodiments, such detail is intended to be instructive rather

than restrictive. It will be appreciated by those skilled in the art that many variations may be made in the structure and mode of operation without departing from the scope of the invention as disclosed in the teachings herein.

<div align="center">*   *   *</div>